TEM study on pit-formation on the end of threading dislocations in MOVPE-GaInN/GaN

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Introduction

In recent years there has been remarkable progress in growth process for good quality films of GaN and its alloys. GaN films grown on an α-Al_2O_3 (0001) substrate by metalorganic vapor phase epitaxy (MOVPE) usually contain threading dislocations of 10^8-10^9/cm^2 when a conventional two-step method [1] is adopted. The density of dislocations has been reduced to the order of 10^6/cm^2 by applying an epitaxial lateral overgrowth (ELO) method or its modified one. [2-4] However, threading dislocations, which are larger in density than in other III-V compounds such as GaAs, still remain in GaN films. It is known that such threading dislocations become the origin of degradation of light emitting diodes (LEDs) and laser diodes (LDs) in their life time and emitting efficiency. The present authors [5] found that the threading dislocations have strong influence to the growth process of GaInN/GaN: A typical V-pit is formed on the end of a threading dislocation. The pits grow to large hollows on the surface of GaInN on further deposition of GaInN and then cause the formation of a two-story-structure in a thick GaInN layer. Sun *et al*. [6], Chen *et al*. [7] and Wu *et al*. [8] also reported the formation of V-pits in GaInN/GaN multiple quantum wells. Northrup *et al*. [9] made theoretical consideration on the origin of the V-pit formation. In this study, cross sectional transmission electron microscope (TEM) observation was performed to analyze the V-pits. The detail shape of the pit and the dependency on Burgers vector of the threading dislocation are also discussed.

Experimental Procedure

An $Ga_{0.2}In_{0.8}N$(100 nm)/GaN(2 μm)/LT-AlN(50 nm)/α-Al_2O_3(0001) specimen was prepared by the MOVPE method using trimethylgallium (TMG), trimethylindium (TMI), trimethylaluminum (TMA) and ammonia with a carrier gas of H_2, where LT-AlN stands for an AlN buffer layer deposited at a low temperature. The growth temperatures were 800 C for Ga InN, 1060 C for GaN and 650 C for LT -AlN, respectively. The detail conditions of the growth was described previously [10]. Thin foil specimens for cross sectional TEM observation were made within Ar^+ ion mill as well as an FIB (focused ion beam) apparatus. Observation was carried out with an electron microscope JEM-2000EX/T operated at 200kV.

Results and Discussion

Figure 1 shows a typical bright field (BF) image of GaInN/GaN/LT-AlN/α-Al_2O_3. Threading dislocations run upwards in GaN and penetrate into GaInN. It is seen that every threading dislocation has a pit on the end. Burgers vector ***B*** of each threading dislocation was determined by a conventional visible-invisible examination in two-beam images. As the result, dislocations labeled 1, 4, 5, 6 and 8 in Fig. 1 have Burgers vector of $\boldsymbol{B}=\boldsymbol{a}=\langle 2\bar{1}\bar{1}0 \rangle/3$, being edge dislocations, and those labeled 2, 3, 7 and 9 have Burgers vector of $\boldsymbol{B}=\boldsymbol{a}+\boldsymbol{c}=\langle 2\bar{1}\bar{1}3\rangle/3$, being mixed dislocations. It is confirmed that a V-pit is formed irrespective of the type of dislocation. Unfortunately, screw dislocations ($\boldsymbol{B}=\boldsymbol{c}=[0001]$) were not found in the specimen. It is not yet clarified if a screw dislocation is terminated by a V-pit. However, the fraction of screw dislocations is usually as small as a few percents in MOVPE-GaN [11]. Therefore, the density of threading dislocations can be estimated by counting the number of pits on the surface unless plural dislocations gather in group.

Figure 2 shows an enlarged image of a V-pit. The pit starts to grow at about 50nm from the interface of GaInN/GaN. This strongly suggests that the critical thickness for V-pit formation is 50 nm for the present specimen.

However, The value for the critical thickness is still controversial. The formation of V-pits depends upon the magnitude of strains around the threading dislocation. The actual chemical composition of GaInN lattice-matched to GaN is different from the nominal one due to the composition-pulling-effect. [5,12] The pit has a shape of an open hexagonal inverted pyramid with $\{1\bar{1}01\}$ planes. Close inspection revealed that the some pits have other small facet planes of $\{h\bar{h}0l\}$ such as $\{1\bar{1}02\}$ and $\{2\bar{2}01\}$. The appearance of facets of $\{2\bar{2}01\}$ near the apex of the inverted pyramid is thought to have a notable effect in opening of the threading dislocation core. The formation mechanism of V-pits will be also discussed in terms of the stability of atomic arrangement near the dislocation core.

Conclusion

The TEM observation revealed the following characteristics of V-pits on GaInN/GaN.

(1) A V-pit is formed on the end of threading dislocation one by one irrespective of Burgers vector, $\boldsymbol{B}=\boldsymbol{a}$ or $(\boldsymbol{a}+\boldsymbol{c})$.

(2) The dislocation density can be estimated by counting the number of the pits on GaInN/GaN.

(3) The formation of V-pits has a critical thickness which is about 50 nm in $Ga_xIn_{1-x}N$(x~0.2).

(4) The V-pits have small facet planes $\{h\bar{h}0l\}$ other than $\{1\bar{1}01\}$.

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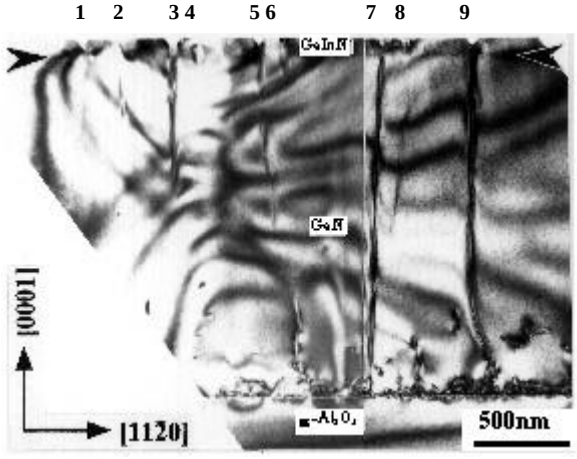

Fig.1 Cross sectional bright field image of GaInN/GaN

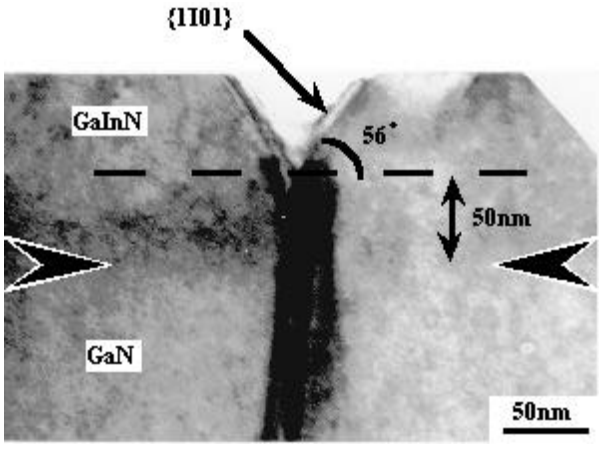

Fig. 2 Enlarged image of a V-pit in GaInN layer.